CARB Heavy-Duty OBD Update

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SAE OBD TOPTEC

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Pasadena, CA

Outline

- Background
- Why OBD for Heavy-Duty Vehicles?
- Requirements
    - Implementation Schedule
    - Monitors
    - Standardization
    - Testing
- Current Status

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Background

- OBD systems currently only required on passenger cars, light-duty trucks and medium-duty vehicles and engines (OBD II)
- Engine Manufacturer's Diagnostic (EMD) systems required on all 2007 MY and subsequent HDEs
  - No standardized requirements and less comprehensive than HD OBD
  - Circuit continuity monitoring , functional monitors of the fuel system, EGR system, and PM trap

Background (cont'd)

- Board Hearing on July 21, 2005
- Board adopted staff's proposal
- Modified text of the proposal available September 9, 2005 with a 45 day comment period
- Formal adoption of the regulation expected by December 2005

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Diesel Emissions are Unhealthy

- **NOx** = precursor to ozone, a lung irritant
- **Diesel PM** = toxic air contaminant (TAC)
  - Identified as TAC in August 1998
  - Contains over 40 substances identified as TACs
  - Carcinogenic in humans & animals
  - Associated with increases in lung disease, heart disease, & mortality
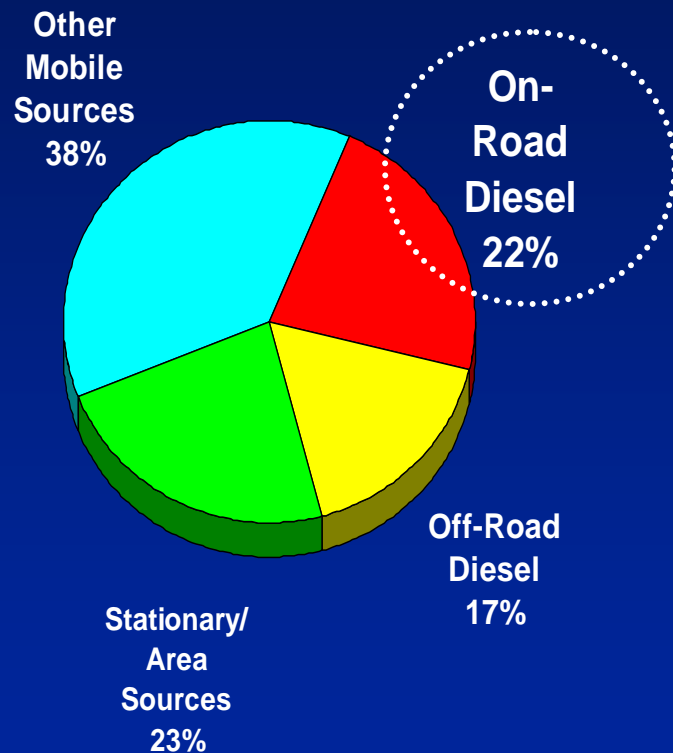
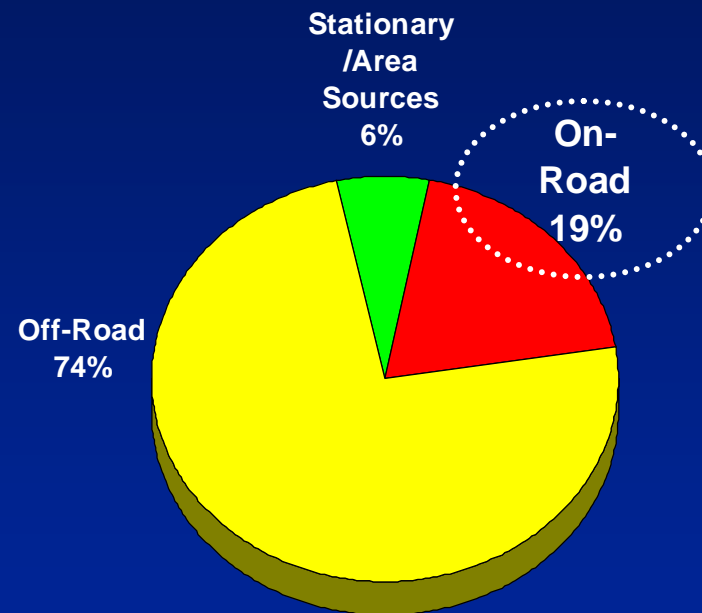*California Environmental Protection Agency*

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Heavy-Duty Diesel Emissions are Substantial

## NOx

Other Mobile Sources 38%

On-Road Diesel 22%

Off-Road Diesel 17%

Stationary/Area Sources 23%

Diesel PM

Stationary/Area Sources 6%

On-Road 19%

Off-Road 74%

Source: EMFAC state-wide projection for 2010

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Why wasn't OBD required for Heavy-Duty before now?

- Heavy-duty engines have traditionally lagged behind in the use of electronic engine controls and advanced emission controls including aftertreatment

- More stringent emission standards starting in 2007-2010 are changing that

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Potential Technologies for HD Diesel Engines in 2010
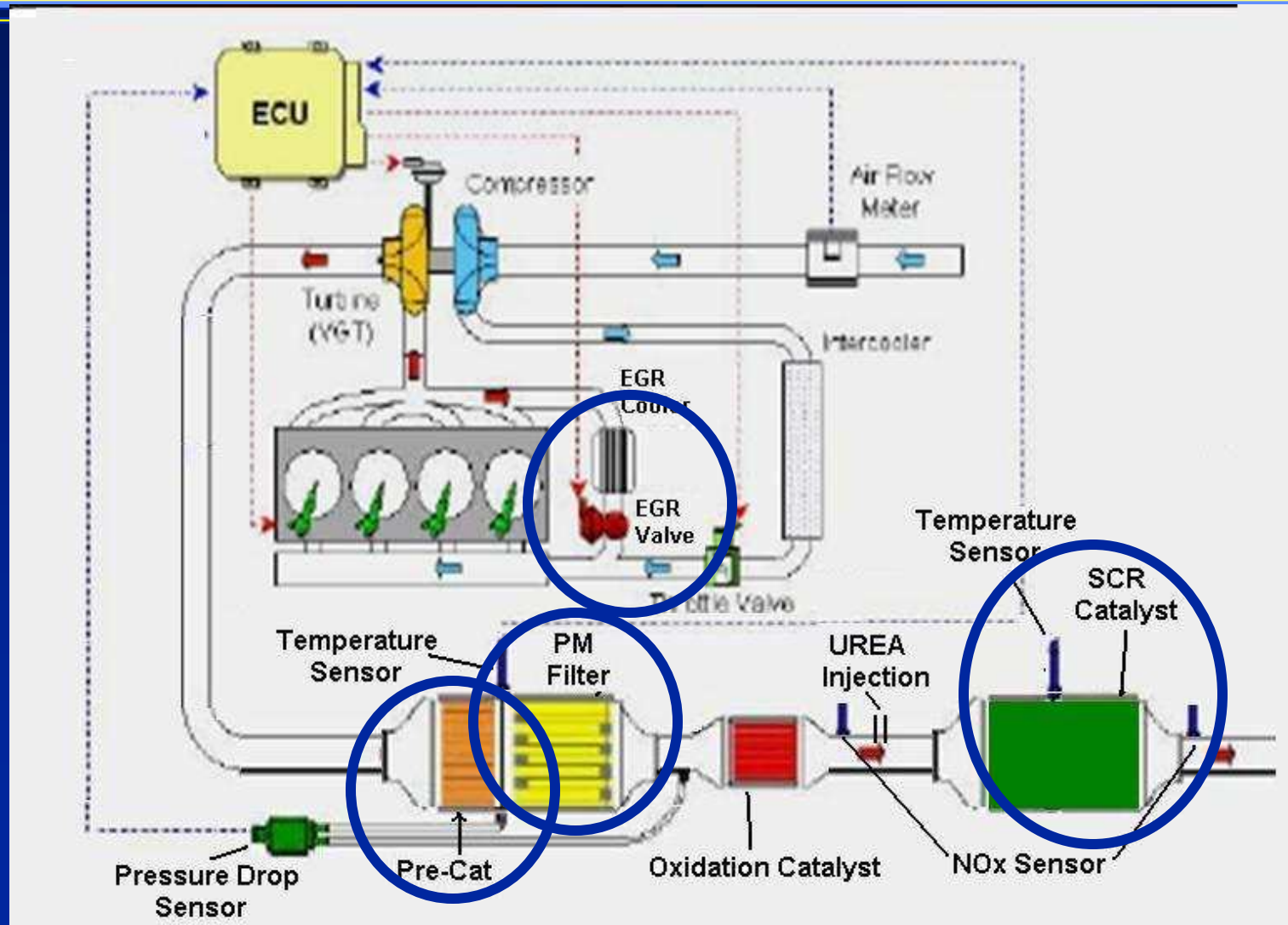
Why OBD for Heavy-Duty Vehicles?

- OBD ensures emission control components are working and vehicle maintains low emissions in-use

- Assist mechanics in diagnosis & repair

- Potential for incorporation into road-side and fleet self-inspections

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Requirements

- Very similar to OBD II: All emission control components would be monitored for deterioration/malfunctions

- Applies to both Otto-cycle (Gasoline) and Diesel engines/vehicles

- Other requirements similar to OBD II (e.g., Standardization, In-use ratio, PVE testing)

- Phase-in begins in 2010

- Full implementation in 2016

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Proposed Requirements

- Threshold monitoring
  - Warning light on when emissions increase X%
  - 8-10 per engine
- Non-threshold monitoring
  - Functional, rational, electrical
  - 75-100 checks per engine
- OBD testing and validation
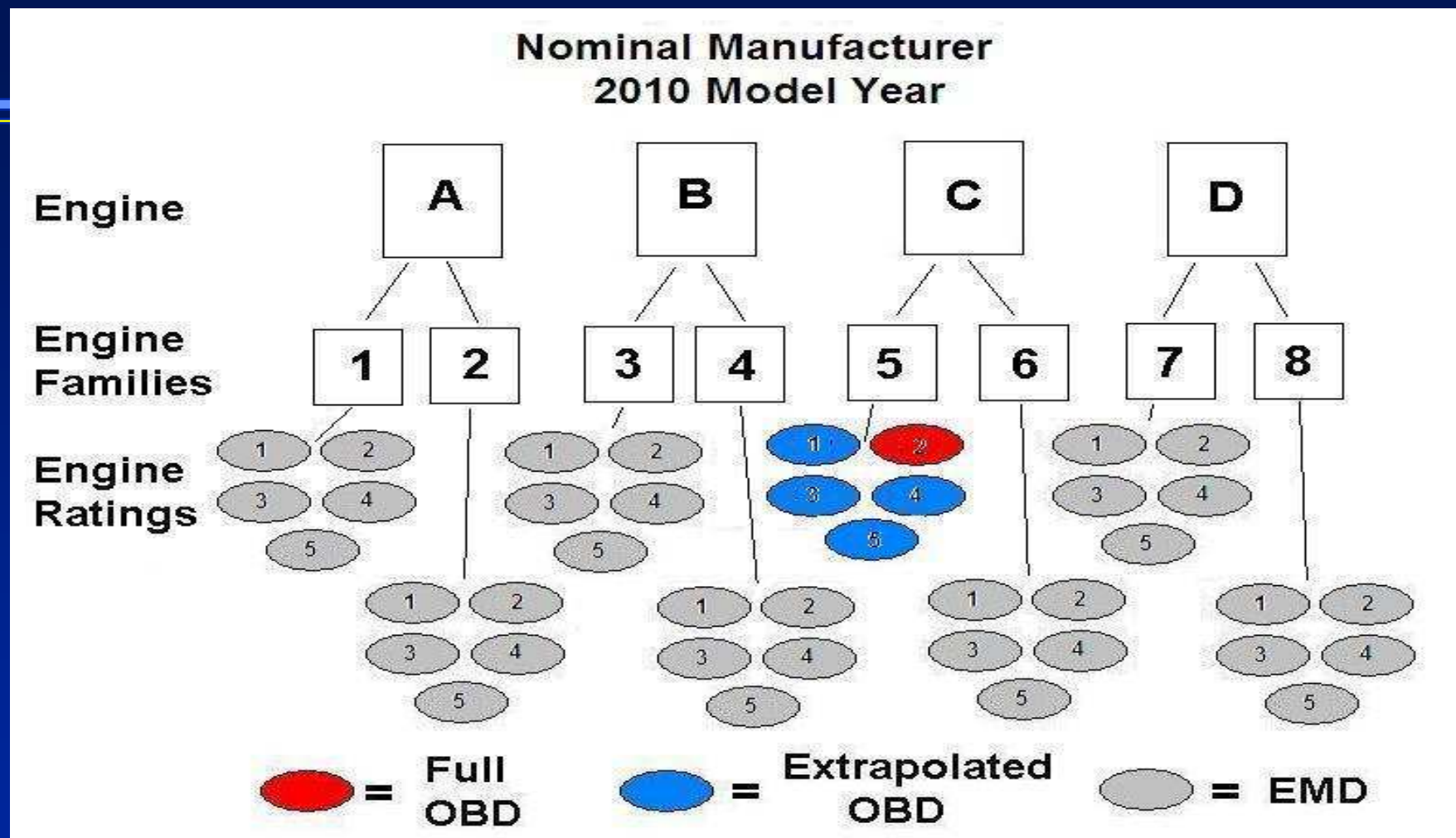 - Pre- and post-production; by engine manufacturer

Threshold Monitoring

- Most important systems (8-10), e.g.
  - PM filter
  - EGR
  - NOx catalyst
  - Fuel System
- Thresholds ('light on') set at multiples of emission standard, e.g.
  - PM filter   5X initially   3X later
  - NOx catalyst   2.5X "   2X "
  - Others (typical)   2.5X "   2X "

Phase-in

- Gradual, 6 year phase-in
  - Addresses workload; test facility limits
- Full system requirements
  - 2010:   1 rating of 1 engine family
  - 2013:   All ratings of 2010 family, 1-2 more representative ratings
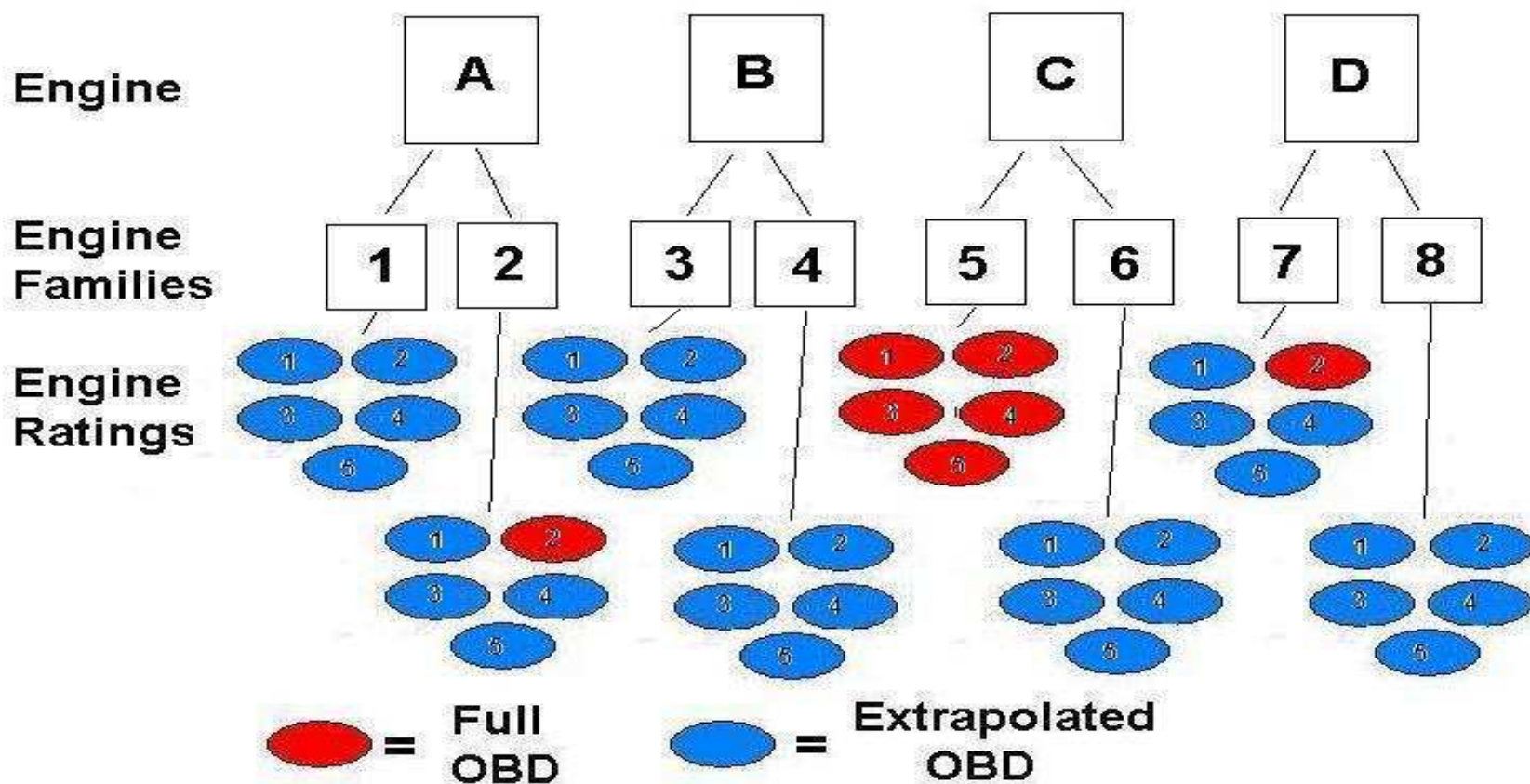 - 2016 : All engines/ratings

Initial Phase-in

Nominal Manufacturer 2010 Model Year

Engine: A, B, C, D

Engine Families: 1, 2, 3, 4, 5, 6, 7, 8

Engine Ratings: 1, 2, 3, 4, 5

= Full OBD
= Extrapolated OBD
= EMD

Partial Phase-in

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Monitoring Requirements

- Targets all engine emission control components

- Prioritizes requirements and stringency based on the emission impact of the component

- Ensures the most important controls (regardless of which emission controls a manufacturer uses) are monitored appropriately

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Diesel Engine Major Monitors

- Fuel System

- Misfire

- EGR System

- Boost Pressure Control System

Fuel System Monitoring

- Requirement: Detect malfunctions that increase emissions to:
  - PM std + 0.02 or 2.5 times the std for NMHC, CO, or NOx (for 2010-2012 model years)
  - PM std + 0.02 or 2.0 times the std for NMHC, CO, or NOx (for 2013+ model year)

- If failure of the component cannot exceed these emission levels, only a functional check is required

Fuel System Monitoring cont'd

- Fuel control parameters that must be monitored
  - Fuel system pressure control
  - Fuel injection quantity
  - Fuel injection timing
- Additional requirement: Detect fault if closed loop system:
  - Fails to enter closed loop
  - Defaults out of closed loop
  - Control authority reaches limits

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Misfire Monitoring

- Requirement for 2010-2012 MY:
  - Detect misfire occurring continuously in one or more cylinders
- Requirement for 2013+ MY engines equipped with sensors capable of detecting combustion/combustion quality (e.g., HCCI engines):
  - Detect misfire that causes emissions to exceed:
    - PM std + 0.02 or 2.0 times the std for NMHC, CO, or NOx
  - Monitor during entire speed and load range

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Misfire Monitoring (cont'd)

- Full-range, intermittent misfire monitoring necessary
  - Aggressive use of EGR and other concepts such as HCCI cause engine to operate near combustion limits at various speeds and loads

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EGR System Monitoring

- Requirement: Detect EGR system faults before emissions exceed:
  - PM std + 0.02 or 2.5 times the std for NMHC, CO, or NOx (for 2010-2012 model years)
  - PM std + 0.02 or 2.0 times the std for NMHC, CO, or NOx (for 2013+ model year)

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EGR System Monitoring

- EGR parameters that must be monitored:
  - EGR Flow Rate (high and low)
  - EGR Response Rate
  - EGR Cooling System Performance
- Additional requirement: Detect fault if closed loop EGR system:
  - Fails to enter closed loop
  - Defaults out of closed loop
  - Control authority reaches limits

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Boost Pressure Control Monitoring

- Requirement: Detect fault before emissions exceed:
  - PM std + 0.02 or 2.5 times the std for NMHC, CO, or NOx (for 2010-2012 model years)
  - PM std + 0.02 or 2.0 times the std for NMHC, CO, or NOx (for 2013+ model year)

Boost Pressure Control Monitoring

- Boost pressure control parameters that must be monitored:
  - Under and over boost malfunctions
  - Slow response (VGT systems only)
  - Charge air undercooling
- Additional requirement: Detect fault if closed loop system:
  - Fails to enter closed loop
  - Defaults out of closed loop
  - Control authority reaches limits

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Diesel Engine Aftertreatment Monitors

- NMHC Catalyst
- NOx Catalyst (Lean NOx and SCR)
- NOx Adsorber
- PM Filter

NMHC Catalyst Monitoring

- Requirement for 2010-2012 MY:
  - Detect conversion efficiency fault before NMHC emissions exceed 2.5 x standards
  - Functional monitor to detect fault if:
    - Insufficient exotherm to achieve PM filter regen
    - Insufficient NO_2 feedgas generation for SCR
    - No NMHC conversion on clean-up/guard catalysts
- Requirement for 2013+ MY:
  - Same as above except detect fault before NMHC emissions exceed 2.0 x standards

NOx Catalyst Monitoring
(Lean NOx and SCR)

- Requirement for 2010-2012 MY:
  - Detect following faults before NOx emissions exceed the standards by:
    - NOx std + 0.30 g/bhp-hr
  - NOx conversion efficiency
  - SCR reductant delivery

- Requirement for 2013+ MY:
  - NOx std + 0.20 g/bhp-hr

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NOx Catalyst Monitoring
(Lean NOx and SCR) (cont'd)

- Additional requirements for 2010+ MY: Detect a fault if:
  - Separate reductant tank empty or filled with non-reductant
  - Feedback control of reductant:
    - Fails to enter closed loop
    - Defaults out of closed loop
    - Control authority at limits

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NOx Adsorber Monitoring

- Requirement for 2010-2012 MY:
  - Detect NOx adsorber capability fault before NOx emissions exceed the standards by 0.3 g/bhp-hr
- Requirement for 2013+ MY:
  - Same as above except detect faults before NOx emissions exceed the standards by 0.2 g/bhp-hr

NOx Adsorber Monitoring (cont'd)

- Additional requirements for 2010+ MY: Detect a fault if:
  - Insufficient active/intrusive injection to achieve desorption of NOx adsorber
  - Feedback control of NOx adsorber or active/intrusive injection system:
    - Fails to enter closed loop
    - Defaults out of closed loop
    - Control authority reaches limits

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PM Filter Monitoring

- Requirement for 2010-2012 MY:
  - Requires malfunctions be detected before PM emissions exceed the higher of:
    - 0.05 g/bhp-hr; or
    - PM std + 0.04 g/bhp-hr

- Requirement for 2013+ MY:
  - Detect fault before PM emissions exceed the higher of:
    - 0.03 g/bhp-hr; or
    - PM std + 0.02 g/bhp-hr

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PM Filter Monitoring (cont'd)

- **Additional requirements for 2010+ MY:**
  - Detect: (before NMHC emissions exceed 2.5x (2010) or 2.0x (2013+) std)
    - too frequent regeneration
    - catalyzed filter NMHC conversion efficiency
  - Functional monitor for:
    - Incomplete regeneration
    - Missing substrate
    - Insufficient injection for active PM filter regeneration
  - Detect a closed loop regeneration system fault:
    - Fails to enter closed loop
    - Defaults out of closed loop
    - Control authority reaches limits

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Diesel Engine Additional Monitors

- Exhaust Gas Sensors
- VVT System
- Cooling System

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Exhaust Gas Sensor Monitoring

- **A/F sensors:**
  - For upstream sensors,
    - Detect fault before 2.5x/2.0x (2010/2013+) standards or PM standard plus 0.02 g/bhp-hr
  - For downstream sensors in 2010-2012:
    - Detect fault before aftertreatment thresholds exceeded (NMHC 2.5 x standard, NOx standard plus 0.3 g/bhp-hr, PM 0.05 g/bhp-hr, or PM standard plus 0.04 g/bhp-hr)
  - For downstream sensors in 2013+
    - Same as above but with final aftertreatment thresholds (NMHC 2.0 x standard, NOx standard plus 0.2 g/bhp-hr, PM 0.03 g/bhp-hr, or PM standard plus 0.02 g/bhp-hr)

Exhaust Gas Sensor Monitoring (cont'd)

- NOx sensors:
  - 2010-2012 MY: Detect fault before aftertreatment thresholds exceeded
    - NOx standard plus 0.3 g/bhp-hr;
    - 0.05 g/bhp-hr PM or PM standard plus 0.04 g/bhp-hr
  - 2013+ MY: Same as above except detect fault before final aftertreatment thresholds
    - NOx standard plus 0.2 g/bhp-hr;
    - 0.03 g/bhp-hr PM or PM standard plus 0.02 g/bhp-hr

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Exhaust Gas Sensor Monitoring (cont'd)

- Additional requirements for 2010+ MY: Detect the following faults for all sensors:
  - Circuit/out-of-range faults
  - Feedback faults that cause an emission control system to default out of closed loop
  - Insufficient performance of the sensor for use for other OBD monitors
  - Heater performance and circuit faults

VVT System Monitoring

- Requirement: Detect faults before emissions exceed:
  - 2010-2012:   2.5x standards, or PM standard plus 0.02 g/bhp-hr
  - 2013+:   2.0x standards, or PM standard plus 0.02 g/bhp-hr
- Detect following faults:
  - target error
  - slow response

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Cooling System Monitoring

- Requirement: Monitor cooling system (e.g., thermostat, ECT sensor) for proper performance:
  - must reach minimum temperature necessary to enable other OBD monitors or any emission control strategy within a reasonable time

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Cooling System Monitoring (cont'd)

- Will likely require engine manufacturers to set <u>upper</u> and lower bounds on amount of heat that coach builders may take out of system during warm-up
  - e.g., max heat removed from the engine side of the thermostat during warm-up

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Gasoline Engine Monitors

- Same as light-duty OBD II monitoring requirements (section 1968.2)
  - Emission thresholds tied to 1.5 or 1.75 x standards for major monitors
  - Evap leak check for 0.150" instead of 0.020"
  - No A/T diagnostics

Gasoline Engine Monitors (cont'd)

- Alternate-fueled engines
  - Subject to requirements for gasoline engines (even if they are derived from a diesel engine)
  - Must meet HD OBD requirements in 2020+

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Diesel and Gasoline Engine Monitors

- CV System
- Comprehensive Components
- Other Emission Systems

CV System Monitoring

- Gasoline requirement: Detect disconnection of the system between:
  - the crankcase and CV valve, or
  - the CV valve and the intake manifold.
  - Or, design the systems to avoid disconnection
- Diesel requirement: Submit plan for review:
  - Combination of detection and, more likely, design of the system to avoid disconnection

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Comprehensive Component Monitoring

- Required to monitor electronic components that are used/inputs to the engine controller and that:
  - can cause a measurable emission increase during any reasonable driving condition, OR
  - affect any other OBD monitors
- Requirement: Detect following faults:
  - circuit and rationality faults for input components
  - functional faults for output components
- Monitors not tied to emission thresholds

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Other Emission Control System Monitoring

- Required to monitor other emission control systems that are:
  - not identified under the other monitoring sections, OR
  - identified as a comprehensive component, but not corrected or compensated for by an adaptive control system
- Manufacturers required to submit a plan detailing monitoring strategy and malfunction criteria for ARB approval

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Standardization Requirement

- Standardization is a key element of OBD

- Minimum defined set of data would have to be output to a scan tool

- Because of phase-in schedule in 2010-2012, standardization requirements not applied until 2013 model year

Standardization Requirement

- Standardized Items include:
  - Communication Protocol
  - Connector Configuration & Location
  - Test Modes/Commands
  - Data Parameters (e.g., fuel pressure, injection timing)
- SAE J1939 and ISO 15765 protocols are allowed

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Testing Requirements

- **Certification Demonstration Testing**

- **Production Vehicle Evaluation (PVE) Testing**
  - Verification of Standardized Requirements
  - Verification of Monitoring Requirements
  - Verification of In-Use Monitoring Performance

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Certification Demonstration Testing

- As part of the certification application, manufacturers would be required to submit a limited set of test data

- Failed "thresholds" parts are installed on the engine and then emission tested by the manufacturer

- To reduce burden on manufacturer, data from only a few engines required each year

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Demonstration Testing

- Purpose: Assurance that emission threshold monitors are calibrated correctly (e.g., 2.5x standards)
- Test engine selection:
  - For 2010 MY, test one engine & aged aftertreatment system
  - For 2011-2012 MY, test 1-2 engine & aged aftertreatment system depending on number of engine families
  - For 2013+ MY, test 1-3 engine & aged aftertreatment systems depending on number of engine families
    - 1-5 engine families => 1 demo engine
    - 6-10 engine families => 2 demo engines
    - 11+ engine families => 3 demo engines

Demonstration Testing (cont'd)

- Testing Requirements:
  - Testing of all emission threshold monitors
  - Engine dyno emission testing
  - Single fault testing (one fault at a time)
  - "De-greened" engine plus emission control system aged/representative of full useful life
  - Install "threshold" component
  - Perform applicable emission test (FTP or SET) to show that malfunction is detected and MIL is illuminated at/before required emission levels

Demonstration Testing Summary Diesel

Component	Testing Requirement
	** PM std + 0.02 g/bhp-hr
Fuel System	high/low pressure @ 2-2.5xstd** high/low quantity @ 2-2.5xstd** advanced/retarded timing @ 2-2.5xstd**
Misfire	2010-2012: no testing 2013+: misfire @ 2xstd**
EGR	high/low flow @ 2-2.5xstd** slow response @ 2-2.5xstd** cooler performance @ 2-2.5xstd**
Boost Control	under/over boost @ 2-2.5xstd** VGT slow response @ 2-2.5xstd** undercooling @ 2-2.5xstd
NMHC Catalyst	efficiency @ 2-2.5xstd and detect empty can

Demonstration Testing Summary Diesel (cont'd)

Component	Testing Requirement
	** PM std + 0.02 g/bhp-hr
NOx Catalyst	efficiency @ std+ 0.2-0.3g/bhp-hr reductant delivery @ std+ 0.2-0.3g/bhp-hr empty can detection
NOx Adsorber	trapping @ std+ 0.2-0.3g/bhp-hr and empty can detection
PM Filter	filtering @ 0.03-0.05g/bhp-hr or PM std + 0.02-0.04 g/bhp-hr empty can detection
VVT System	target error @ 2-2.5xstd** slow response @ 2-2.5xstd**
Exhaust Gas Sensor: A/F Sensor	upstream: performance @ 2-2.5xstd** downstream: performance @ 2-2.5xNMHC std, NOx std+ 0.2-0.3 g/bhp-hr, PM 0.03-0.05 g/bhp-hr or PM std + 0.02-0.04 g/bhp-hr
Exhaust Gas Sensor: NOx Sensor	performance @ NOx standard plus 0.2-0.3 g/bhp-hr, PM 0.03-0.05 g/bhp-hr, or PM standard plus 0.02-0.04 g/bhp-hr

Demonstration Testing Summary Gasoline

Component	Testing Requirement
Fuel System	primary feedback rich/lean @ 1.5xstd secondary feedback rich/lean @ 1.5xstd
Misfire	misfire @ 1.5xstd
EGR	high/low flow @ 1.5xstd
Cold Start	each component @ 1.5xstd
Secondary Air	high/low flow @ 1.5xstd
Catalyst	efficiency @ 1.75xstd empty can
VVT System	target error @ 1.5xstd slow response @ 1.5xstd
Exhaust Gas Sensor	performance @ 1.5xstd other @ 1.5xstd

Demonstration Testing (cont'd)

- Submission of test data:
  - Data required to be submitted <u>prior</u> to certification
- Confirmatory Testing: Manufacturer has to make test equipment available to ARB upon request so ARB can run the same tests and confirm the results

PVE Testing

- Assurance that the OBD system is working properly in-use and meets the requirements of the regulation

- Testing done close to the start of engine production to identify potential major problems that need to be fixed as early as possible

- Verification of the following required:
  – Standardized Requirements
  – Monitoring Requirements
  – In-Use Monitoring Performance

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Verification of Standardized Requirements

- Purpose: To verify that every engine and vehicle variant properly communicates within ISO and SAE specifications to a generic scan tool

- Test vehicle selection:
  - For 2013+ MY engines, test 10 production vehicles per engine family
  - For 2016+ MY, test five production veh/eng family if no vehicles fail testing for two consecutive years
  - For 2019+ MY, test three production veh/eng family if no vehicles fail testing for three consecutive years

Verification of Standardized Requirements (cont'd)

- **Testing Requirements:**
  - Use standardized engineering-type test equipment
    - ARB approval of testing equipment required
    - Standardized verification software/standardized hardware for test equipment/vehicle interface
    - Software initiates test and generates report
    - Testing takes about 20 minutes per vehicle
  - Testing to be done within either three months of the start of engine production or one month of the start of vehicle production, whichever is later

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Verification of Monitoring Requirements

- Purpose: To verify that each and every OBD monitor can detect a malfunction, store a fault code, and illuminate the MIL
- Test engine/vehicle selection:
  - Test 1 to 3 production <u>vehicles</u> based on number of demonstration test engines:
    - 1 demo engine => test 1 vehicle
    - 2 demo engines => test 2 vehicles
    - 3 demo engines => test 3 vehicles
  - Test results to be submitted within six months of the start of engine production or three months of the start of vehicle production, whichever is later

Verification of Monitoring Requirements (cont'd)

- Testing Requirements:
  - Single fault testing
  - No emissions tests or threshold components
  - Vehicle testing
  - No dyno required (but chassis dyno can be used if you want)
  - Install malfunctioning component/simulate malfunction (e.g., bad component, breakout box)
  - Operate vehicle in monitoring conditions until MIL is on and fault code is stored
  - Testing typically takes 2-4 weeks to complete

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Verification of In-Use Monitoring Performance

- Purpose: To verify that the OBD monitors are running frequently in-use
- Test Vehicle Selection:
  - Group vehicle applications/emission control architecture together where in-use monitoring performance is expected to be similar
  - Grouping is based on three vehicle application categories
    - Line-hauls, urban delivery, and all others
  - Submit test plan, which includes groupings, number of vehicles, and where data will be collected, for ARB approval

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Verification of In-Use Monitoring Performance (cont'd)

- Testing Requirements:
  - Collect rate-based data to be representative of every grouping
    - Usually requires data from a minimum of 15 or more vehicles within a grouping
  - Data accessible via a generic scan tool
    - Usually collected from a small sample of dealers when vehicles are in for service/maintenance
  - Data results to be submitted within 12 months after introduction of vehicles into commerce

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Status

- Air Resources Board adopted staff's proposal on July 21, 2005

- 15 day notice was finalized with some minor changes and clarifications and made available September 9, 2005

- Staff to develop enforcement regulation in 2006

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Summary

- Requirements similar to OBD II

- Vast majority of monitoring requirements have been previously demonstrated

- Some requirements will be challenging but technically feasible given the leadtime

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CARB Website

- http://www.arb.ca.gov/msprog/obdprog/hdobd reg.htm